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AUTHOR Sisson, Roger L.
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ABSTRACT

Engineering has much to offer the field of education in bridging the gap between social sciences and teaching by utilizing scientific findings and experience to improve ongoing educational programs and to create new ones. Partial cause of failures at attempts for educational innovation can be found in the lack of appropriate design and implementation studies which could be provided by educational engineers. To remedy these failures, three recommendations are made: (1) In the near future, all participants in the introduction of a social change must become conscious of the need for engineering design information. (2) The profession of educational engineer should be established, along with schools which train professionals to design complex social systems. (3) The educational engineer should interact with both management and science. He can help the social scientist see more clearly the kinds of problems he must work on and help the administrator see more clearly what is feasible in regard to change. Presently engineering skills are missing in most attempts at educational change. Educational engineers could assist in these processes by designing systems and alternatives, planning implementation, and implementing change. (VJ)

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AN ENGINEER IN READING LAND

by

Roger L. Sisson

GOVERNMENT STUDIES & SYSTEMS, INC.
3401 Market Street
Philadelphia, Pennsylvania 19104

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About five years ago, somewhat by accident, I shifted my principal concern from enginnering - particularly the engineering of complex information systems - to the world of education. About two years ago I was introduced to the vast continent in that world called Reading. I tried earnestly, with my engineering background, to make sense out of the wonders of the continent of Reading. I think I am beginning to see some of the features of this continent; some of the hills and chasms, of which there appear to be many. This is the story of the humble engineer in reading land.

THE LAY OF THE LAND.

My map of the reading continent looks like this (Figure 1): There is one country called Educational Research. In this country people run around in little circles trying to find a speck of gold in fields of dust. They make little studies as to whether text book "A" is better than text book "B", or whether you should present the word CAT before the word DOG in teaching children to read. This land appears to be very dusty and the specks of gold are few and far between.

There are several small countries - the Basic Science Nations - which contain people doing research that is not immediately related to reading. These countries are called Psychology, Sociology and Artificial Intelligence. They are separated from the rest of the reading continent by a deep chasm crossed only once in a while by a lonely traveller. The people in these small countries are trying to understand the geology of the land. They would like to be able to

predict where gold might be found, although they are less interested in the gold itself, than in how to predict. They are doing proper science, and they seem to largely communicate the results within their own country.

Finally, there is a country covering the bulk of the continent called Teaching, a large confused mass, covered with fog most of the time. Once in a while there is a traveller between the countries of the Educational Research and Teaching. This appears to occur whenever someone in Teaching needs to rationalize a prejudgment as to how to improve reading.

The chasm which separates Teaching and Educational Research from the Sciences is very deep indeed.

My engineering orientation would lead me to expect to find another country (Figure 2), one that is adjacent on one hand to the Sciences, and on the other to the large country of Teaching. In such a country - we might call Engineering - I would expect to find citizens whose main job it is to travel from one border to the other. They carry knowledge of where the gold might be found, from the small Science countries, to those who are actively looking for the gold in Teaching. This country of Engineering would be populated by people whose background and orientation propels them to understand and know the results of science (although not necessarily do it). On the other hand, they are also motivated to help the individual citizens of the country of Teaching to find gold, by use of not only the scientific findings, but whatever experience and art they have acquired in performing this job previously.

The main business in the country of engineering is to bridge the existing chasm; to utilize scientific findings and previous experience to improve ongoing educational programs and to create new, and improved programs. Engineering is the function which makes innovation - about which there is so much talk - possible.

Here are some examples of the lack of engineering; not all related to reading, but all from education.

About two years ago the School District of Philadelphia undertook to install and design a complete community school. The project started because a new school, the Hartranft School, was to be built. The school authorities felt that this would be a good opportunity to develop the idea that education would proceed more smoothly if the school became a true community center. It was hoped that the school would serve not only for regular and after school activities but for adult education, as a local community health center, as a recreation center and a general community meeting place. The physical facilities were to be designed to facilitate this approach.

In order to implement this idea it is obvious that a number of groups have to be involved: community groups, local churches, and other active local organizations, as well as the city recreation and health departments and, possibly, State and Federal agencies such as the employment service.

The associate superintendent most directly involved with this project was faced with the question of how to deal with these various

groups; who should he talk to first, which groups should he talk to separately and which together, should he talk to leaders or to the entire membership, what kind of public relations were required, and so on. Since there is no engineering, the associate superintendent did not know to whom he could turn and did the only thing possible. He turned to some people at local universities - people from the Science country. He called in a sociologist and a social psychologist. After exploring the problem for several hours, these scientists said in effect: "This is a very interesting problem. We'll come back with a proposal for a three year program. We will study this problem and develop a real understanding of the sociology of this community." They could not cross the chasm; they were still doing science.

You can imagine what happened. The superintendent was involved making decisions tomorrow or the day after, and needed immediately applicable advice. And the scientists were going to perform a three year scientific exploration!

The associate superintendent thought he was talking to people who would play the role of engineer (although he was not consciously aware of that desire) and the scientists were playing their true role of observing the phenomena as a basis for study, the result of which would be scientific know-how, not decisions.

In another case, in a western state, a school principal heard about Advanced Placement (providing good students with college level work in high school, so that they can start college at an advanced level.) In May he said to his staff, by September our school will

have an Advanced Placement program! There was no thought of engineering a system for providing this kind of training. As a matter of fact, it takes several years to develop an Advanced Placement program. Not only does one have to hire and train special staff, but certain groups of students have to be started into the proper track, so that by the time they are juniors and seniors, they have the background necessary for the advanced courses. Engineering takes time.

A major eastern, urban school district recently undertook a study of whether to decentralize and if so how. (It was proceeding carefully, because it did not want to get into the same sort of difficulties which arose in New York City). A commission was established with 58 people and a $30,000 budget. Their job was to "engineer" the new decentralized organization with its community interaction and administrative procedure

The head of the staff for this commission was a former city planner This man had directed the expenditure of many millions of dollars for the engineering of facilities. For example, he told me that a typical high school required about $600,000 for engineering. I asked him then, how is it possible that a physical facility, for which we have a great deal of design and building experience, and which depends on well established physical science, requires $600,000 and yet the very complex system problem of redesigning an entire school district with all of its human and social interactions is to be done for only $30,000! Even he, who had the engineering concept, who had used engineering himself, did not recognize the utter inconsistency in these two levels of funding.

At least one case in which the lack of engineering is clear has been carefully documented by Neal Gross and his associates then at Harvard University (Gross, N., Giacquinta, J., Bernstein, N. An Attempt to Implement a Major Educational Innovation: A Sociological Inquiry, Report #5, Center for Research and Development on Educational Differences, Harvard University, 1968).

The Harvard group were purely observers of an effort to implement a relatively basic change in a school district. However, the time schedule is not made completely clear in Gross' report. Apparently, the ideas for the change were developed during the summer of 1966, the innovation was initiated in the late fall of 1966, (while school was in progress, of course), was given additional impetus in January of 1967, and was evaluated by Gross extensively in May of 1967. The time scale alone gives us a clue that no attention was paid to the engineering of this change. Engineering takes time and it would have been almost impossible to have done it between June and September or October of one year.

The basic nature of the change was to convert elementary school classes from classical highly structured programs to relatively unstructured situations in which the individual child would be able to explore more fully his own paths of learning and his own capabilities. The innovation was to be implemented only in those rooms where the teacher was agreeable. Gross wished to examine this study because he wishes to refute the notion that innovation of this type failed because of initial resistance to change. The history of the school was

such that it was clear that the staff and the administration were most favorably inclined toward innovations and were willing to try them out. Many of the teachers were new and were not tied to any traditions of the school and/or the profession.

A study of Gross' report shows that this particular innovation is bogged down by the most trivial things: the materials required for the new classroom situation were not available. (Even simple planning would have obviated this problem.) The staff was not trained, not even oriented, in the way in which the children might behave in the new classroom situation. Therefore, they confused free expression with undisciplined behavior. As a result of this and other problems, the staff became quickly disenchanted. The administration, in the absence of planning for such contingencies, did nothing about it except to call in ad hoc consultants, which made the matter worse. By May the innovation had essentially failed, and the school returned to classical methods. The absence of engineering had caused another fiasco.

Although the country of engineering does not exist in reading, there are a few towns who try to perform the engineering function. The title IV or regional labs translate scientific results into practical curriculum and learning systems. Some of them have taken on the next job of seeing that these systems are properly implemented in Teaching.

Given, admittedly, a bias as a result of my engineering background, I would like to see the Educational Research country (of the few gold

specks) gradually wither away, to be replaced by the country of Engineering. To do this we must give specific attention to who will be the citizens; who will perform the engineering function and how they will be trained. I recommend, for example, the creation of new schools, (or curriculums within schools of education), devoted to teaching people how to implement and design innovations. See Appendix I. These people would not necessarily learn a lot of sociological irrelevancies about diffusion and dissemination, they would learn some hard facts about engineering, such as,

> engineering takes time and money;
>
> a key result in engineering is the preparation of detailed specifications for the equipment, materials and processes to be implemented;
>
> in the social sector, engineering requires the involvement of the future teachers through their participation in the implementation process, and awareness of the design process;
>
> engineering involves the use of the best tools possible for predicting the consequences of various designs (and not the advocacy system);
>
> promising alternatives must be carefully considered in terms of performance and implementation feasibility (not just one favorite approach.)

I have had occasion to put these notions into practice in helping the Office of Education develop the Targeted Research and the Development Program for Reading and in developing a plan for the National Right to Read Effort. I hope you will have occasion to read about these plans. (You will hear about the latter in Miss Hamblet's presentation.) As you read through these and other proposals think about whether the engineering function has been recognized and properly scheduled.

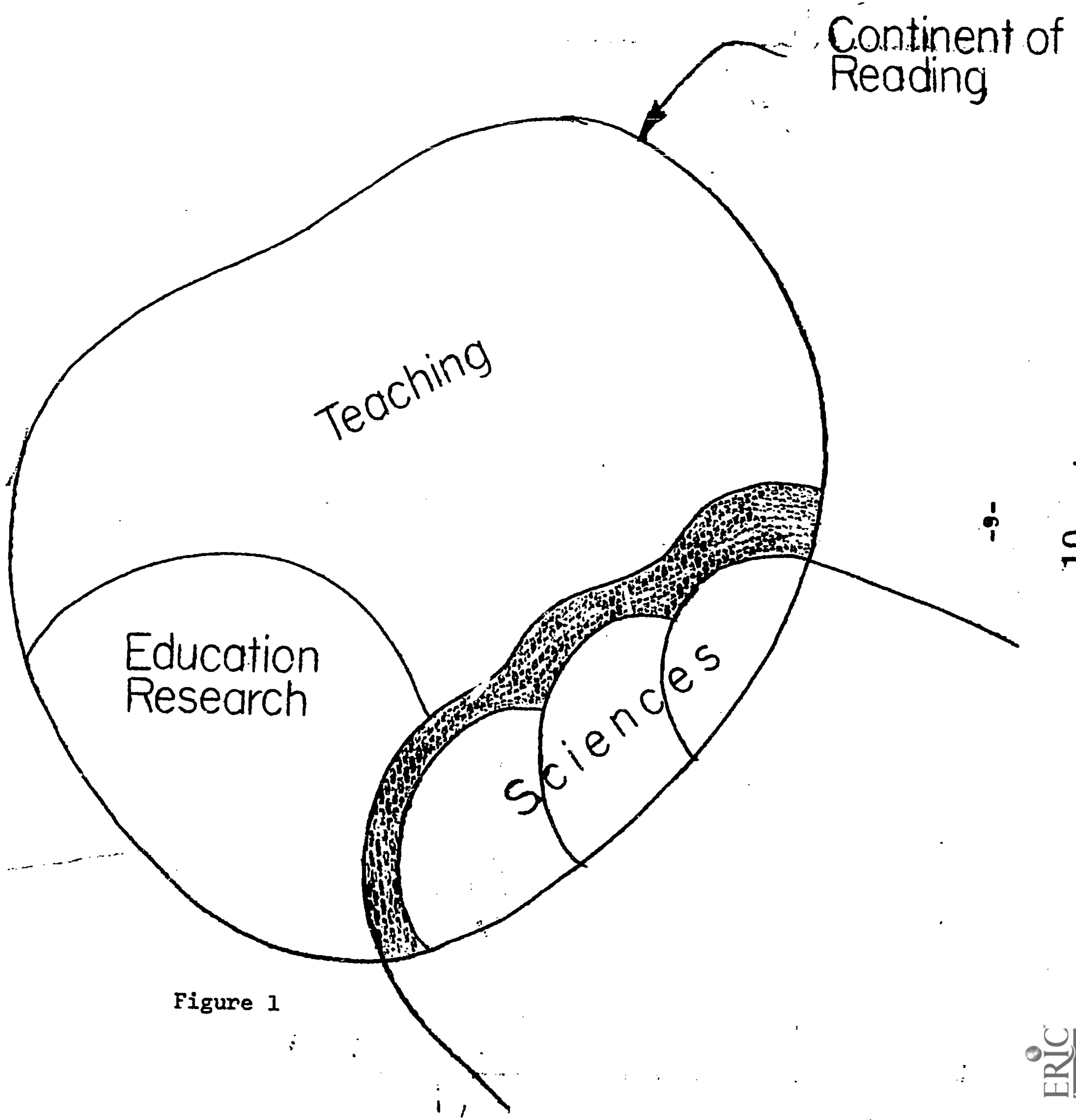
Continent of Reading
Teaching
Education Research
Sciences

Figure 1

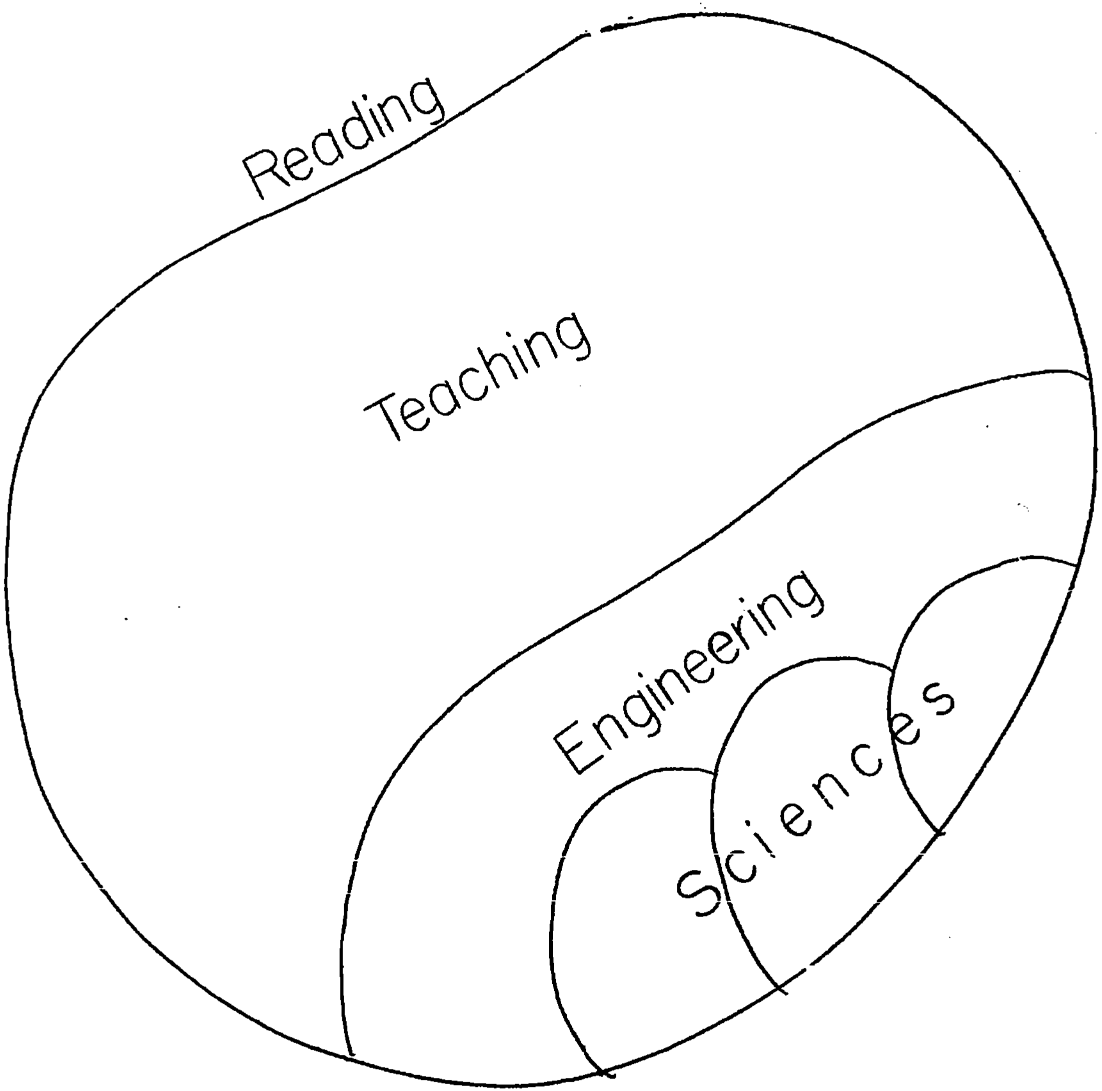

Figure 2

APPENDIX I

Recommendations

If it is true that the major reason for the failure of educational improvement is the lack of ›ropriate design and implementation studies, then it is fairly clear what must be done.

I will divide my recommendations into three parts; short, intermediate and long term.

Short term

In the near future, all participants in the introduction of a social change must become conscious of the need for engineering design, Legislators and managers who initiate change should especially require submission of system designs, specifications and implementation programs. People responsible for operating new innovations and new systems should not accept management responsibility until it is clear how the system will operate, how it will react to possible problems and how it will be implemented. This design information should be in terms of procedure and physical facilities, and more important, in terms of the interactions between people affected, communities and client groups. This kind of design requires a great deal of data collection, particularly data about the attitudes of people who will be affected by the system. It requires careful design of alternative systems, a specific means of evaluating these alternatives, and as we have said, careful implementation and planning.

Since there is no profession of educational engineering, it is not clear who will do all this. There are, however, a number of people now unhappy with the role of scientist, or otherwise trained to take an engineering point of view, who could be involved in this process if it was specifically recognized that their involvement was desirable. The profession of operations research is closely related to engineering. Many operations researchers would undertake the task of designing decision systems for management using whatever scientific principles and prior art there is available. Analysts responsible for industrial product introduction face similar engineering problems. Many of these people would be interested in applying their techniques to the public sector.

Intermediate Term of Recommendations

The principle step that should be taken to insure that future systems are more properly designed, is to establish the profession of educational engineering and to develop appropriate curriculum or schools. These schools will train professionals to design complex social systems using all of the science and art available. They will be full professional schools in the same sense that schools of electrical engineering or aeronautical engineering provide the engineers in those disciplines.

Long term

In the long term, the existence of an educational engineering profession would interact with both management and science. Social scientists would see more clearly the kinds of problems they must work on, because the engineers would have identified those design and implementation problems with which they have difficulty. Managers would see more clearly whom they might call on in order to improve their systems, and would have better ideas of what is and is not feasible in a given time in regard to change.

APPENDIX II

Technical Description of the Role of Engineering

In order to describe engineering, I will give my definition of three common processes. These processes are an integral part of our culture; they are: science, engineering, and management. The definitions will be given in terms of a flow chart (see the Figure 3.) Each box of this chart illustrates a process or series of activities related to science, engineering, or management. All of these in turn are oriented toward an ongoing social process (at the bottom of the figure) which provides a product or service (education) for the communities involved. A process might be a private corporation, a physical project (to build a bridge), local school district, a total reform program for a State's educational process - whatever one is interested in improving.

Science

The game of science consists of producing "know-how." It is "conclusion-oriented." It produces ideas, general models and theories which describe the properties of the world around us. More important, science permits us to predict what will happen if we change the environment. Even more important, these theories indicate possibilities for change which we could not preceive without the appropriate know-how. Examples from the world of physical science are obvious. Newton's theories permit us to predict how mechanical structures will behave before we build them. The airplane and atomic energy are new alternatives made accessible by appropriate scientific discovery.

The Production and Use of Knowledge

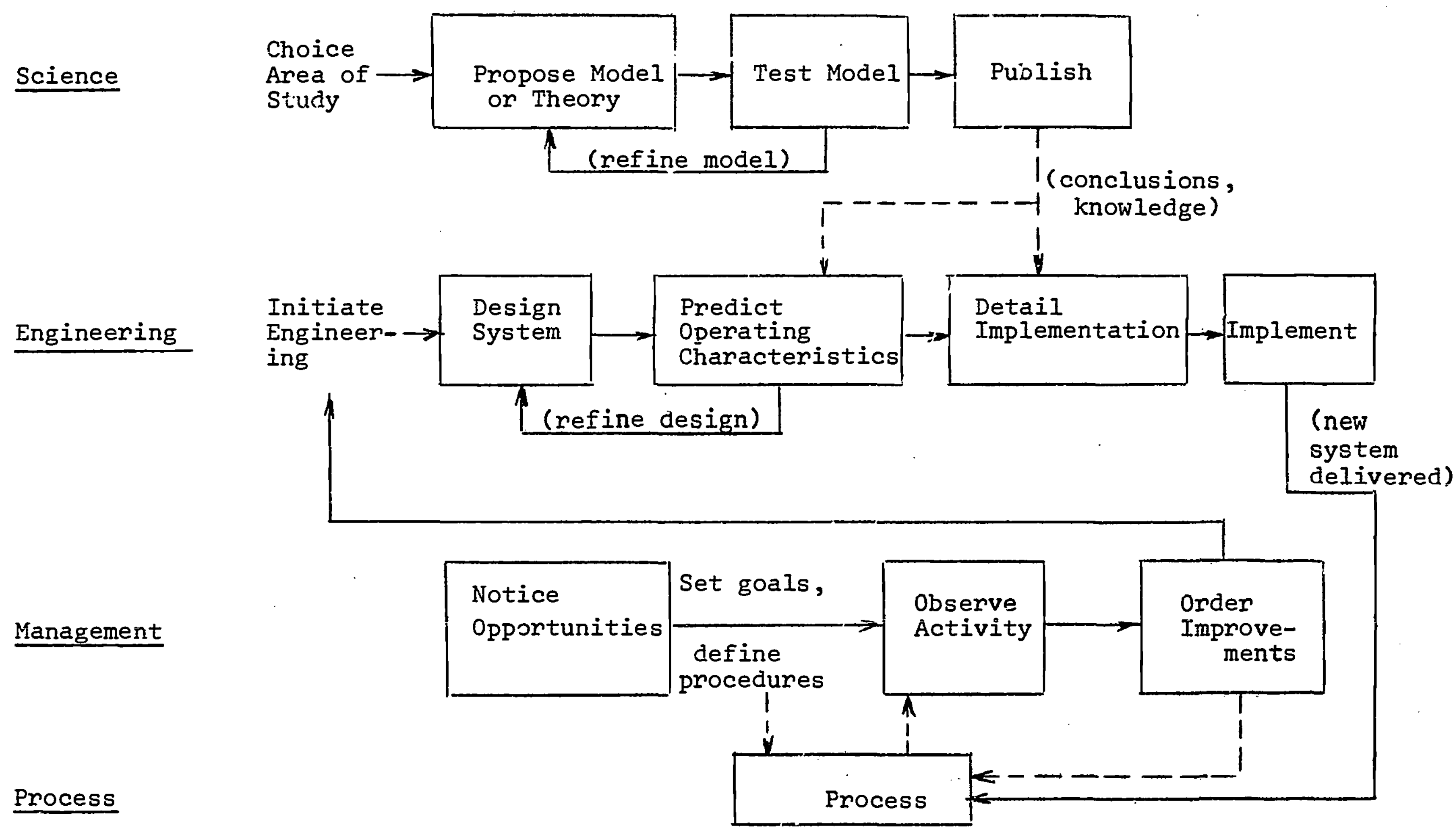

Figure 3

The upper part of Figure 3 indicates how science proceeds. A scientist chooses (presumably with a great deal of freedom) an area of study. The scientists then proposes a model or theory of the phenomena he has chosen to study; that is, he makes some effort to find basic patterns or invariant features of that part of the world. The models or theories are then tested to show that they are indeed predictive. Since the first models are likely to be poor predictors, this process of proposing models and testing them iterates until satisfactory predictors are obtained. The results are then published. The goal of thescientists is to publish papers or, in general, to disseminate the knowledge, the know-how he has found. Science proceeds as a sub-activity within all modern nations.

Engineering

If we concentrate, for a moment, to the world of physical structures and devices, the second extremely important activity is engineering (engineering in the sense of design and implementation.) The nature of engineering is shown in the middle part of the figure. Based on some impetus, usually from a management process, the engineer is given the task of changing or constructing a new system by which some process will be carried out. To do this he goes through the steps shown: he designs several systems which might be appropriate. He predicts the operating characteristics of these systems and the costs to construct and run them. He then coooses from among these alternative designs the one most likely to satisfy the management

needs (this is where "values" come in) within given cost restraints. Having chosen a particular design, he schedules in detail the implementation of the system and proceeds to supervise that implementation. Through this series of steps the changed or new system comes into being.

There is a strong interaction between science and engineering. It _is_ possible, however, to engineer systems without any applicable science--in fact, we do it all the time. It is possible to build a bridge without any science of strength of materials or of structures. People put logs across streams--an engineering task--long before we had any such sciences. However, if science has produced predictive models and disseminated the knowledge, then the process of engineering is greatly facilitated. The results of science can be used to (1) indicate designs not hitherto feasible (such as atomic plants for producing electrical power), (2) facilitate the comparison of design alternatives by permitting the rapid computation of operating characteristics, and (3) facilitate the design of the implementation plan by predicting how the environment will react to the system. For example, the science of soil mechanics assists the bridge designer in determining whether or not the bridge will sink into the embankment. Various formal techniques, such as the critical path method, have evolved for facilitating the implementation phase.

The availability of scientific findings also permits a reduction in design cost, in ultimate system cost, and a reduction of redundancy, i.e. of "safety factors." If it is difficult to predict how a structure

will behave, we must make the members very thick--design with large safety factors. If we have a good theory of materials and structures then we can compute the load handling capabilities of a structure quite exactly and can use very small safety factors, reducing costs significantly. The same kind of safety factors are built into social systems.

It is important to recognize the two phases of engineering, just discussed: the product or system design, and the implementation design (which may include what in industry would be called marketing functions.)

Management

The third important process is that of management, illustrated at the bottom of the figure. One of the manager's main functions is to notice opportunities, opportunities for providing service to the community. In the private sector it occurs as an opportunity to make a return on an investment; in the public sector it occurs as an opportunity to do good and to gain social approbation. Based on these observed opportunities, the management sets goals for the people who carry out the process; sometimes they also define specific operating procedures to be followed. They observe the process activity to keep the process headed toward desired goals (and to notice additional opportunities.) As difficulty arises, management orders changes in the process to keep it directed toward goals. The goal-setting process is, of course, definitely tied to cultural and

personal values. It is a very complicated process in the public sector. Nevertheless, in most specific cases the value determining process can be identified.

Sometimes a manager notices that the process is not headed in the right direction and that minor corrections do not seem to help. Or perhaps a major technological change has occurred which he can take advantage of. In either of these cases, he might call in appropriate engineering personnel and have them design and implement a more major change in the process. The system changes implemented by the engineer may affect the way in which the manager observes process activity (his information system), the way he directs it, the way he orders changes, and to some extent the facility he has for finding opportunity. Most of the system changes affect the way the process -education- is carried out.

Another key job of the manager is to motivate the people carring out the process to do so in an appropriate manner.

Examples of this science-engineering-management interaction abound in the physical area. If the process is a manufacturing plant, it is clear that there is science behind the product and the manufacturing processes, that there are engineers who design the plant, the facilities, and the products and implement them, and that there is management to keep the process running.

Application to Social Processes

When we try to apply this sequence of steps in the social area, we will find that the engineering step is almost completely missing. Consider education-a school. There is a superintendent (and his staff) who insures that the process operates properly on a day to day and a year to year basis. There is a considerable body of psychological and behavioral science, which says something about the education process. But who is it to whom one could turn to "engineer an improved school system?" There is no identifiable group whose job it is to carefully design systems, examine system alternatives, to plan the implementation, and implement changes in any of our social processes.

Because management attention is focused on the identification of opportunities and more specifically on the operation of existing processes, they do not have training nor the time for the design (engineering) effort, nor time for the analysis of the results of science to see if it is applicable. Scientists may have more time, but do not have the design orientation nor the training for engineering. A separate discipline is needed.